Financial market misconduct and public enforcement: The case of Libor manipulation

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ABSTRACT

Using comprehensive data on London Interbank Offer Rate (Libor) submissions from 2001 through 2012, we provide evidence consistent with banks manipulating Libor to profit from Libor-related positions and to signal their creditworthiness during distressed times. Evidence of manipulation is stronger for banks that were eventually sanctioned by regulators and disappears for all banks in the aftermath of the Libor investigations that began in 2010. Our findings suggest that the threat of large penalties and the loss of reputation that accompany public enforcement can be effective in deterring financial market misconduct.

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1 Introduction

Manipulation of the London Interbank Offer Rate (Libor) impaired trust in financial markets. Many banks were involved, with great potential harm to the real economy, as hundreds of trillions of dollars are tied to Libor. Regulators responded by starting large-scale investigations and imposing historically high penalties for the banks involved. The main reasons for Libor manipulation and the effectiveness of the enforcement measures in discouraging future manipulation, however, remain largely open questions.

We shed light on these questions by examining the costs and benefits of Libor manipulation. We start by exploring banks' incentives to manipulate Libor and test for the presence of manipulation. Once we establish the main reasons for Libor manipulation, we ask whether evidence of manipulation abated after regulators launched formal investigations. We also examine whether enforcement affected only the behavior of banks that were sanctioned or also of other banks that were not. To support our findings, we estimate the gains accruing to banks from Libor manipulation compared to the penalties imposed by regulators.

The British Banking Association (BBA) introduced Libor in 1986 as a measure of the inter-bank borrowing rate; it is now a crucial reference rate for spot and derivatives contracts. Allegations of Libor manipulation were first made in a 2008 *Wall Street Journal* article by Mollenkamp and Whitehouse. Widespread investigation ensued, led by the Financial Services Authority (FSA in the UK) and the Commodity Futures Trading Commission (CFTC in the US). Nine large international banks reached settlement agreements with regulators, and cumulative penalties approached $9 billion.[1]

While regulators launched formal investigations soon after the first allegation of Libor manipulation, no changes were implemented in the way Libor is computed until 2013, when its administration was transferred

[1]The penalties imposed on banks as of August 2017 were: Deutsche Bank $3.5 billion, Union Bank of Switzerland $1.5 billion, Royal Bank of Scotland $1.1 billion, Rabobank $1.1 billion, Societe Generale $0.6 billion, Barclays Bank $0.5 billion, Lloyds Bank $0.4 billion, J.P. Morgan Chase $0.1 billion, and Citigroup $0.1 billion. Only fines for fixing foreign exchange rates are higher at about $10 billion. Fines related to the Global Settlement Agreement amount to $1.4 billion.

from the BBA to the ICE Benchmark Administration (IBA).[2] By focusing on the period from 2001 (start of our data) through 2012, we can therefore separate the effect of enforcement actions on incentives to manipulate Libor from other regulatory changes.

In this period, the BBA computed Libor as a trimmed average of the self-reported borrowing costs (Libor submissions) of select groups of panel banks. Panel banks were obliged to report their true borrowing costs and not align their submissions with their own interest. It was always understood that any deviation from this rule would violate general laws and rules on acting in good faith. Yet the system initially lacked proper enforcement, and there were no predetermined penalties for manipulations. Despite its monitoring of the Libor submission process, the only mandate the BBA had was to report inaccuracies to higher authorities. Banks were also not required to submit actual transaction data on borrowing costs, which made it even more difficult for regulators to detect violations. These circumstances suggest a rather low likelihood that manipulation would be discovered.

The first allegations of Libor manipulation suggested that banks were underreporting borrowing costs to appear less risky than other banks (Mollenkamp and Whitehouse (2008)). We call this the "signaling hypothesis." Ultimately, attention shifted to another important reason for Libor manipulation; that is, banks aligned their submissions in the direction of their Libor exposure in an attempt to move Libor in the desired direction and profit from their Libor-related positions (Snider and Youle (2014)). We call this the "cash flow hypothesis."

We test both hypotheses empirically in a two-stage procedure. In Stage 1, we estimate proxies for banks' incentives to manipulate Libor. In Stage 2, we then test the signaling and the cash flow hypotheses by relating our proxies for incentives to manipulate Libor to banks' future Libor submissions. The null hypothesis of no association between the incentives to manipulate and future submissions is based on the BBA rule, which prohibits banks from aligning submissions with their own interests.

Because banks are not required to release detailed information on their interest rate exposures, we follow

[2] Details on Libor computation and reforms are provided in Section 3.

Flannery and James (1984) and Acharya and Steffen (2015) and estimate proxies for incentives to manipulate Libor as sensitivities to bank equity returns. Under the cash flow hypothesis, aligning individual submissions with Libor exposure pushes Libor in the desired direction. This increases cash flows to panel banks and, ultimately, banks' equity valuations. Under the signaling hypothesis, underreporting of borrowing costs reduces panel banks' perceived riskiness, which investors would reward with higher bank valuations. We therefore regress each bank's excess returns on changes in Libor and changes in bank's Libor submissions while controlling for bank risk. The estimated coefficient on changes in Libor is our proxy for incentives to manipulate Libor due to the cash flow hypothesis. The estimated coefficient on changes in Libor submissions is our proxy for incentives to manipulate Libor due to the signaling hypothesis. To account for time-series variation, we use a rolling window approach.

The literature suggests that bank equity sensitivities are informative about interest rate exposures, and we provide corroborating evidence using balance sheet data for a subset of banks. Still, equity prices may not always accurately reflect all relevant information, suggesting that the estimated equity sensitivities will be noisy. Any measurement error in incentives to manipulate Libor would likely bias our results against finding evidence for Libor manipulation.

We use data on Libor submissions from 2001 through 2012 from Bloomberg for the 12 most important Libor currency-maturity pairs as identified by Wheatley (2012): United States dollar (USD), Great Britain pound (GBP), Japanese yen (JPY), and Swiss franc (CHF) for the *1*-, *3*-, and *6*-month maturities. When we relate incentives to manipulate Libor to future Libor submissions (Stage 2), we control for a bank's credit default swap (CDS) spread and size, domestic yield, and measures of bank-level risk, as well as bank and time fixed-effects within each currency-maturity pair.

We find strong empirical evidence consistent with the cash flow hypothesis. In the full sample, banks' future Libor submissions are positively and significantly related to banks' Libor exposures. This is consistent with banks attempting to manipulate Libor in order to profit from their holdings of Libor-related products. A one-standard deviation increase in the Libor exposure of a panel bank implies a 0.07 basis point increase in its average submission over the subsequent month. Such an increase is economically important; given the large notional value of contracts tied to Libor, even a fraction of a basis point can result in large cash flow transfers among investors. For example, Deutsche Bank calculated that, as of September 30, 2008, it could gain or lose as much as 68 million Euro per one-basis point change in Libor (Eaglesham (2013)). As expected, we find more pronounced evidence for the cash flow hypothesis for the Libor with the biggest notional value of interest rate derivatives outstanding (the *3*-month USD), because these are the contracts that would produce the highest gains from manipulation.

The evidence for the signaling hypothesis in the full sample is statistically insignificant. Only when signaling is most beneficial — namely, when banks' borrowing costs are high, funding illiquidity is high, and banks are credit constrained — do we find evidence for the signaling hypothesis. The fact that signaling is operant only in times of distress is broadly consistent with evidence for the signaling hypothesis in studies that compare Libor submissions to alternative proxies for banks' borrowing costs. Signaling may also be costly, because it leads to lower Libor and reduces the interest rate revenues of banks with overall positive exposure to Libor. Also, signaling works only if used infrequently, as investors otherwise can learn about the manipulation and take it into account when estimating banks' credit risk.

Next, we examine how the evidence for Libor manipulation varies with regulatory enforcement. Without clear monitoring of Libor submissions at the beginning of our sample period, expected costs of manipulation appeared to be low. This changed in the aftermath of the Libor investigation. Even without the costs related to loss of reputation, penalties imposed by regulators alone approached $9 billion. Several employees involved in fraudulent transactions were dismissed, and many leading bankers resigned. A former UBS and Citigroup trader was sentenced to eleven years in prison.

While the first allegations of Libor manipulation surfaced in 2008, the BBA and many authorities initially disparaged the claims. It was not until 2010-2011 that investigations intensified, which was first reported in a *Wall Street Journal* article in March 2011. A year later, in June 2012, Barclays was the first bank to admit to the allegations and to reach a settlement agreement with the regulators.

To analyze the effect of enforcement measures, we therefore test for Libor manipulation before 2011 and after 2010. We use only data pre-2013 so that we do not confound enforcement measures with the regulatory changes to Libor that started in 2013. We focus on Libor manipulation attributable to the cash flow hypothesis, as our evidence suggests that this was the primary reason for manipulation. Moreover, the incentives to manipulate Libor for cash flow reasons are not confined to the crisis periods (as in the signaling hypothesis). As before, to account for time trends in the micro and macro environments, we include several control variables as well as bank and time fixed effects.

We indeed find evidence of manipulation before 2011, but not after 2010. We also find that manipulation was initially stronger for the five banks that were the most severely sanctioned for misconduct than for the non-sanctioned banks. We interpret this as an indication that regulators were by and large correct in assessing which banks manipulated the most. After 2010, manipulation seems absent for all banks, whether sanctioned or not. This suggests that regulators were successful in creating a credible threat of penalties and the loss of reputation for all banks.

To gain further insight into the costs and benefits of Libor manipulation, we next calculate the hypothetical Libor that would have obtained if banks had not manipulated Libor submissions, following the cash flow hypothesis. Given the difference between the actual Libor and the hypothetical Libor, we estimate banks' gains (in terms of market capitalization) from Libor manipulation from 2001 through 2010. The five banks that were penalized most severely reaped total gains from manipulation of $15.39 billion; $4.15 billion stemmed from their own manipulation attempts and the rest from manipulation by other banks. Although gains were realized earlier than penalties, and are thus more valuable, the gains from the banks' own manipulation attempts were lower than the cumulative penalties imposed by regulators. The fines also exclude reputation costs and civil law suits. Our results therefore suggest that the costs of manipulation were substantial, weighing importantly against any future benefits of manipulation.

Our findings are not driven by differences in banks' general exposure to interest rate risk or endogeneity in the estimation of their Libor sensitivities. Results are also robust to changes in the choice of control variables, the length of the rolling window in estimating proxies for incentives to manipulate Libor, the use of either weekly or monthly data, and the precise timing of Libor investigations.

Overall, our evidence suggests that Libor manipulation was primarily driven by the cash flow motive stemming from Libor-related positions and, to an extent, by signaling desires during crisis periods. Most intriguingly, manipulation seems to stop for all banks after regulators launched formal investigations around 2010-2011. This is consistent with the view that enforcement actions with large penalties and the associated loss of reputation can be effective in discouraging financial market misconduct.

2 Related literature

Our paper relates to two streams of the literature — the studies on the cost-benefit analysis of financial market misconduct, and the research on Libor manipulation.

2.1 Enforcement and incentives for financial market misconduct

Motivated by the theory on law and economics (Becker (1968)), we analyze the extent of Libor manipulation through the lens of cost-benefit analysis and show how manipulation declines with enforcement actions of regulators, over time and across sanctioned and non-sanctioned banks. In a similar vein, Madureira, Kadan, Wang, and Tzachi (2009) and Corwin, Larocque, and Stegemoller (2017) show that the Global Analyst Research Settlement in 2003 diminished conflicts of interest in sell-side research. Regulatory scrutiny in the case of Libor manipulation, however, was not immediately followed by changes in rules and regulations. We can therefore isolate the confounding effect of regulatory changes and capture only the impact of enforcement action on the extent of Libor manipulation. Also, as documented by Corwin, Larocque, and Stegemoller (2017), the Global Settlement affected only the behavior of sanctioned banks, while we find that Libor manipulation stopped for both sanctioned and non-sanctioned banks.

Some researchers study the impact of enforcement on financial market misconduct indirectly by analyzing its impact on capital markets. For example, Bhattacharya and Daouk (2002) show that the cost of equity in a country declines after the first prosecution of insider trading. Consistent with that finding, our results suggest that rules without effective enforcement are not enough to mitigate financial misconduct.

Our paper is also related to the literature on incentives for financial misreporting. Bergstresser and

Philippon (2006) and Burns and Kedia (2006) show that performance-based compensation incentivizes managers to manipulate prices through misreporting, earnings management, and fraudulent accounting. Bollen and Pool (2009), Agarwal, Daniel, and Naik (2011), and Ben-David, Franzoni, Landier, and Moussawi (2013) show that pay-for-performance contracts encourage hedge fund managers to manipulate returns. Similarly, we argue that incentives for higher bank valuation (which subsequently determines management bonuses) may drive panel banks to manipulate Libor submissions. Thereby we also add to the discussion on an unethical culture in corporations and in the financial industry (Biggerstaff, Cicero, and Puckett (2014) and Lo (2016)).

2.2 Libor manipulation

The initial allegations of Libor manipulation suggested that banks were manipulating Libor submissions to appear less risky (Mollenkamp and Whitehouse (2008)). Following these allegations, the first academic studies focused on testing the signaling hypothesis and compared Libor submissions to other proxies of borrowing costs. The evidence regarding signaling in Abrantes-Metz, Kraten, Metz, and Seow (2012) is inconclusive. Kuo, Skeie, and Vickery (2012) and Wong (2009), however, argue that Libor was too low during the height of the financial crisis of 2007-2008. Similarly, Monticini and Thornton (2013) find evidence of underreporting in Libor for at least some banks. Furthermore, the FSA stated in its final notice to Barclays in 2012 that Barclays rates submitted between September 2007 and May 2009 were too low because of possible negative media perceptions about its earlier relatively high Libor submissions.[3] Overall, this is broadly consistent with our findings that signaling is confined to times of distress, when underreporting Libor submissions is most beneficial.

Banks have large holdings of contracts tied to Libor, prompting Snider and Youle (2014) to explore the possibility of Libor manipulation driven by banks' incentive to profit from their Libor-sensitive assets. This possibility is aligned with the anecdotal evidence. According to Vaughan and Finch (2017, p. 154),

[3]https://www.fca.org.uk/publication/final-notices/barclays-jun12.pdf

individuals responsible for submitting Libor estimates to the BBA were often instructed to align their Libor submissions with their banks' derivative positions. We refer to this type of manipulation as the cash flow hypothesis. In the Snider and Youle (2014) model of the submission process, panel banks balance the cash flow gains from manipulation against the cost of being discovered. Their model predicts a bunching effect around particular submission levels, which they confirm empirically. Youle (2014) builds a similar model based on a non-cooperative game. He uses the model to estimate constant bank-level exposures to Libor that show that Libor was downward-biased during the recent crisis.

We use a broader cross-section of Libor submissions and simultaneously explore the cash flow and signaling hypotheses for Libor manipulation. We show that manipulation can be explained mainly by the cash flow hypothesis and to less of an extent by signaling during crisis times. In contrast to Youle (2014), we estimate time-varying bank-level exposures to Libor. Collusion among banks arises endogenously in our setting from similarities in banks' Libor exposures or signaling desires. Importantly, we also analyze how the extent of Libor manipulation varies with the enforcement actions of regulators.

Wheatley (2012), Duffie and Stein (2015), and Coulter and Shapiro (2014) propose changes in market design to prevent future Libor manipulation. They call for greater reliance on transaction-based measures of borrowing costs and improvement in the method used to calculate Libor. Some of these proposals were implemented in 2013. Our results, however, suggest that public enforcement can be effective in preventing Libor manipulation even without changes in market design.

Finally, our work is related to studies that use multi-factor models to estimate banks' interest rate exposure from equity returns (Flannery and James (1984) and Acharya and Steffen (2015)). We cross-validate this approach using bank balance sheet data.

3 Libor computation and sources of manipulation

After we review the history of Libor computation, we discuss how Libor can be subject to manipulation, and develop our testable hypotheses.

3.1 Libor computation

The British Banking Association introduced Libor in 1986. It has become a major benchmark rate for short-term interest rates and a reference rate for a broad range of spot and derivatives financial contracts. Some $300 trillion of financial assets are tied to Libor, according to Wheatley (2012).

Two important changes have been made in the way Libor is computed. Initially, Libor was based on banks' estimates of other banks' borrowing costs. Starting in 1999, Libor has been based on banks' estimates of their own borrowing costs. The second change came in 2013, in response to the probes into Libor manipulation. Certain less important Libor currencies and maturities were discontinued; individual submissions are no longer publicly available in real time (but with a delay of three months); banks must now name one person who is accountable for Libor submissions, and keep records for auditing purposes; and, perhaps most important, the administration of Libor was transferred from the BBA to the Intercontinental Exchange (ICE).

To isolate the effects of the changes in the way Libor is computed and administered, we focus on the period from 2001 through 2012 (the beginning of the period is determined by data availability). Over this period, Libor was computed by the BBA for 10 distinct currencies and 15 different maturities. We refer to these 150 combinations as currency-maturity pairs.

The daily procedure to compute Libor was as follows. Around 11 AM each weekday, the BBA collected interest rate data for each currency and maturity from panel banks using a survey that required banks to answer a question: "At what rate could you borrow funds, were you to do so by asking for and then accepting inter-bank offers in a reasonable market size just prior to 11 AM?" The number of panel banks varied across time and currencies from 6 for the Swedish krona to 18 for the US dollar. The panel banks' self-reported answers, which we refer to as submissions, were not required to be based on actual transactions, but were supposed to reflect the banks' true borrowing costs. By rule, submissions were not allowed to be aligned with the bank's own interests.[4]

[4] See http://www.bbatrent.com.

Libor was then computed as a trimmed average of the submissions. That is, for each currency-maturity pair, submissions were ranked in descending order from highest to lowest. The highest 25% and the smallest 25% of the submissions were trimmed, and the average of the remaining submissions was published at 12:00 noon as the Libor for that currency-maturity pair. All individual bank submissions were made public at the same time.[5]

Note that, despite the use of the trimmed average, each panel bank's submission is relevant for the ordering of the submissions and the computation of Libor. Consider the four submissions 2%, 3%, 4%, and 5%, and trim the top and the bottom submissions. The average would be computed over submissions 3% and 4%. Now change the 2% submission to 6%. The new average would be computed over submissions 4% and 5%, as the center set changes even though the changed submission is still being trimmed. Thus, trimming does not eliminate panel banks' attempts to manipulate Libor (see also Eisl, Jankowitsch, and Subrahmanyam (2017)).

3.2 Costs and benefits of Libor manipulation

Despite explicit prohibitions, self-reporting indicates that banks' submissions were not necessarily reflecting the banks' true borrowing costs. When manipulating submissions, a bank would weigh the potential gains against the associated costs. We use this trade-off to develop our testable hypotheses.

3.2.1 Incentives for manipulating Libor

The literature and anecdotal evidence suggests two main ways that panel banks could benefit from manipulating Libor. First, panel banks may attempt to manipulate Libor in order to benefit from higher profits on their Libor-related products. This would benefit shareholders through higher bank valuations, while bank traders and managers would benefit through increased pay and bonuses. Panel banks therefore have an incentive to align their submissions with their individual exposure to Libor. A panel bank with a net

[5] Internet Appendix A provides further details on Libor computation.

long position in Libor-related assets would benefit from an increase in Libor, while a bank with a net short position would benefit from a reduction in Libor. This represents the basis for our first hypothesis:

H1: Cash flow hypothesis: Panel banks align their Libor submissions with their individual Libor exposures in an attempt to manipulate Libor and thereby profit from their Libor-related positions.

We expect this type of manipulation to occur most often in currency-maturity pairs with a high notional volume of interest rate derivatives, because these are the contracts most likely held by banks and that would lead to the highest manipulation gains.

The second way a bank can profit from manipulating Libor submissions is by signaling its credit riskiness. Panel banks' submissions are supposed to reflect their true borrowing costs. Market participants could therefore use the submissions to infer panel banks' credit riskiness. This was possible prior to 2013 because all Libor submissions were publicly available in real time.[6] A higher submission by one panel bank (relative to other banks) would indicate that that bank has higher credit risk, which in turn may lower the panel bank's valuation and increase the demand for collateral by its counterparties. To appear less risky, banks may therefore have an incentive to report submissions that underestimate their true borrowing costs. This represents the basis for our second hypothesis:

H2: Signaling hypothesis: Panel banks report low Libor submissions to appear financially sound compared to their peers.

This sort of manipulation can persist only if market participants are unaware of manipulation or if it is difficult to estimate banks' credit riskiness using other sources. In a repeated game, market participants can learn about manipulation and take it into account when estimating banks' credit riskiness. This in turn diminishes banks' incentives for signaling. Lowering Libor submissions may also be costly to banks with an overall positive exposure to Libor. We thus expect signaling to occur mainly when the potential benefits from underreporting are highest, namely, in times of financial distress and for the riskiest banks.

[6] In the new regulation, individual submissions become publicly available after a delay of three months.

Note the important difference between the cash flow and the signaling hypotheses. While the cash flow hypothesis suggests that panel banks' submissions are biased either upward or downward, depending on their net exposure to Libor, the signaling hypothesis suggests that panel banks always bias their Libor submissions downward.

3.2.2 Costs of manipulating Libor

Manipulation of Libor submissions does not come without costs, because banks were explicitly prohibited from aligning submissions with their own interests. The expected cost of manipulation rises with the likelihood of detection and with the potential costs imposed if detected (Becker (1968)).

It was always understood that manipulating Libor would be a violation of BBA rules as well as a violation of general laws and rules on acting in good faith. The Statement of Facts of the Barclays settlement reiterates the BBA rules: "The basis for a Contributor Panel bank's submission, according to the BBA, must be the rate at which members of the bank's staff primarily responsible for management of a bank's cash, rather than a bank's derivative trading book, consider that the bank can borrow unsecured interbank funds in the London money market.... In other words, a Contributor Panel bank's LIBOR submissions should not be influenced by its motive to maximize profit or minimize losses in derivative transactions tied to LIBOR."[7]

During Libor trials, prosecutors also referred to other laws and rules that banks violated: securities laws (by changing the value of Libor-dependent securities), competition laws (by colluding in their submissions), tort laws (by interfering with the benefits that a counter party could expect in some contract), concealment and fraud laws (by hiding the fact that they manipulated Libor to their advantage), and rules on acting in good faith towards their counterparts.

Initially, the system lacked proper enforcement. There were no pre-determined penalties for violations, and it was not clear who was responsible for enforcing the rules. The BBA was supposed to monitor the

[7] Barclays settlement: Statement of Facts, Appendix A, item six. Available at https://www.justice.gov/iso/opa/resources/9312012710173426365941.pdf.

Libor submission process, but it lacked authority to penalize banks. It had the mandate only to report inaccuracies to higher authorities, such as the FSA and the CFTC. Furthermore, the organization of the BBA proved problematic. Its board included bankers — its chair was the CEO of Barclays — which led to conflicts of interest. Finally, banks were not required to submit their actual transaction data on borrowing costs, which made it difficult for regulators to detect violations. All these arguments suggest that the costs of (partially) aligning banks' submission with banks' own interests were initially rather low.

The situation changed when regulators started investigating cases of Libor manipulation. Beyond the financial penalties, which currently total $9 billion, there are costs related to loss of reputation, which could be substantial and even outweigh the costs of penalties (Armour, Mayer, and Polo (2010)). Finally, there are costs to individuals responsible for misconduct. Following Libor enforcement actions, employees involved in fraudulent transactions were dismissed, one was sentenced to 11 years in prison, and many leading bankers resigned, including Barclays' chair, Barclays' CEO, and Deutsche Bank's co-CEOs.

Altogether, the costs associated with manipulating Libor turned out to be high. We therefore expect them to weigh importantly against the benefits of manipulation and diminish its incentives. These costs, however, became known only ex-post. Moreover, even after the first allegations of Libor manipulation in 2008, the BBA argued that Libor continued to be reliable, and many authorities initially contradicted the claims of manipulation. It was only in 2010-2011 that the investigations intensified, and the threat of prosecution became severe. In March 2011, a *Wall Street Journal* article was the first to report that regulators were investigating several banks in their probe of Libor manipulation (Enrich, Mollenkamp, and Eaglesham (2011)). The first bank to admit to the allegations and reach a settlement agreement with the regulators was Barclays in June 2012.

Looking at the time line, we believe that the expected costs of Libor manipulation were initially low, but increased rapidly with the intensity of investigations. We argue that by 2011, with the *Wall Street Journal* article's publication, all banks were aware of regulators' enforcement actions. If improvements in enforcement with potentially high financial and reputation costs is effective in preventing financial misconduct, one would expect Libor manipulation to subside. We limit our analysis to the time before 2013, as we do not wish to confound enforcement measures with the regulatory changes to Libor that started in 2013. This forms the basis for our last hypothesis:

H3: Enforcement and reputation hypothesis: Libor manipulation lessened in the aftermath of the Libor investigations in 2010-2011.

The expected costs of enforcement actions may also vary across banks. If regulators focused their efforts on a predictable set of banks, the costs of manipulation should increase only for the banks that are most likely to be investigated. This appeared to be the case for the Global Settlement in 2003, when analyst affiliation bias disappeared only for the sanctioned banks (Corwin, Larocque, and Stegemoller (2017)). If regulators managed to establish a credible threat of scrutiny using non-predictable criteria, manipulation should decline among all panel banks. To test this prediction, we separately examine banks that were eventually sanctioned and those that were not.

4 Methodology

We develop a three-stage empirical approach for testing our hypotheses. In Stage 1, we estimate proxies for banks' incentives to manipulate Libor. In Stage 2, we test our hypotheses by relating proxies for incentives to manipulate Libor to future Libor submissions. Finally, in Stage 3, we calculate the potential gains for banks from Libor manipulation.

4.1 Banks' incentives to manipulate Libor (Stage 1)

We require a measure for incentives to manipulate Libor under the cash flow hypothesis and a measure for incentives to manipulate Libor under the signaling hypothesis.

For the first measure, we would ideally have high-frequency data on Libor positions for all the panel banks. Unfortunately, such data do not exist because banks are not required to release detailed information on their interest rate exposure. Moreover, banks are exposed to Libor through many different channels other than direct exposure through loans and mortgages; derivatives positions are an important source of the overall Libor exposure. We therefore follow authors who estimate interest rate exposure through sensitivities of bank equity. Flannery and James (1984) show that the sensitivity of bank equity to interest rates is related to the maturity structure of a bank's assets and liabilities. Acharya and Steffen (2015) show that bank equity sensitivities can be used to determine bank's exposure to sovereign debt. Similarly, we conjecture that bank equity sensitivity to changes in Libor reveals a bank's Libor exposure. Using bank equity data is convenient because it also enables us to estimate our second measure, a bank's incentives for underreporting Libor submissions under the signaling hypothesis.

According to both hypotheses, manipulating individual submissions should increase panel banks' market valuations. Under the cash flow hypothesis, aligning individual submissions with Libor exposure pushes Libor in the desired direction, and thus increases cash flows that accrue to panel banks from Libor-related positions. While some investors may have private information about banks' cash flows, ultimately all investors learn about banks' overall profitability, and the accrued cash flows affect a bank's equity valuation. Under the signaling hypothesis, underreporting of borrowing costs reduces panel banks' perceived riskiness. Outside investors reward the lower risk through higher bank valuations. These mechanisms suggest a direct link between a panel bank's equity returns and its incentives to manipulate Libor. We therefore propose to estimate a particular panel bank's incentives to manipulate Libor under both hypotheses in a multi-factor model that expresses bank equity returns as a function of changes in Libor, changes in bank's individual submissions, and control variables.

Because measurement of incentives to manipulate Libor submissions is crucial for our subsequent analysis, we pay special attention to the empirical implementation of the model. We balance several choices. The first choice regards the data frequency. The data are available daily, but Libor and submissions are very persistent (e.g., for the Japanese Yen, the rates often do not change from one day to the next). To avoid stale estimates while preserving a relatively high frequency, we estimate the model using weekly data.

Second, because banks' exposures to Libor may vary substantially over time, we estimate time-varying coefficients using a rolling windows approach. To balance the trade-off between the staleness of estimated coefficients measured over longer windows against the statistical uncertainty of the same coefficients measured over shorter windows, we choose windows of 26-weeks (half a year) (our results are robust to reasonable changes in window length, see Section 8.3).

The third choice regards the set of variables to control for banks' risk exposures. Bank stocks are in many ways different from those of non-financial firms, and the Fama-French and momentum factors do not add much explanatory power to the market model (see, for example, Gandhi and Lustig (2015)). Moreover, financial stocks are typically excluded from the construction of the Fama and French (1992) factors. Therefore, we opt for a parsimonious model and control only for the most important risk factors: the market excess return, bank level credit risk (CDS), and market wide liquidity risk (*VIX*, see Nagel (2012)).

Finally, according to the signaling hypothesis, a bank has greater incentives to underreport Libor submissions when its borrowing costs stand out from those of other banks. Therefore, to estimate incentives for underreporting, we use the difference between the individual Libor submission and a benchmark rate, for which we use the overnight indexed swap (OIS) rate, which unlike Libor cannot be manipulated.

To summarize, using weekly data, we estimate rolling window regression separately for each panel bank i and for each currency-maturity pair:[8]

$$\begin{aligned} r_{i,t} - r_{f,t} &= \alpha + \beta_i^{\Delta Libor} \Delta Libor_t + \beta_i^{\Delta Sub} \Delta (Sub_{i,t} - OIS_t) + \\ &\quad \beta_i^{\Delta CDS} \Delta CDS_i^x + \beta_i^{Mkt} (r_{Mkt,t} - r_{f,t}) + \beta_i^{\Delta VIX} \Delta VIX_t + \epsilon_{i,t}, \end{aligned} \quad (1)$$

where r_i is the (dollar-denominated) weekly return on bank i's equity; r_f is the weekly *3*-month USD overnight indexed swap (OIS) rate; $Libor$ is the official Libor for a particular currency-maturity pair; and

[8]This implies that the sensitivities (βs) in Eq. (1) should be further indexed by currency-maturity pair (c, m). We omit these subscripts to simplify notation.

$Sub_i - OIS_t$ is the difference between bank i's Libor submission and the OIS rate for that currency-maturity pair.[9] $\Delta Libor$ and $\Delta(Sub - OIS)$ are the weekly changes of these quantities from $t-1$ to t. Among the controls, ΔCDS_i^x denotes the change in the CDS of bank i in excess of the cross-sectional average; $(r_{mkt} - r_{f,t})$ are market excess returns; and ΔVIX are changes in the Chicago Board Options Exchange Market Volatility Index. All variables are measured as of week t.

According to the cash flow hypothesis, the sensitivity to Libor $\beta^{\Delta Libor}$ depends on a panel bank's net exposure to Libor. This can be either positive or negative. According to the signaling hypothesis, investors react negatively to higher submissions, implying a negative sign for the estimated sensitivity to Libor submissions $\beta^{\Delta Sub}$.

4.2 Testing hypotheses (Stage 2)

In Stage 2, we test if either the estimated sensitivity to changes in Libor (cash flow hypothesis), or the estimated sensitivity to changes in Libor submissions (signaling hypothesis), or both, predict panel banks' average Libor submissions over the following month. The null hypothesis of no association between the incentives to manipulate Libor and future submissions is based on the BBA rule that explicitly prohibits banks from aligning submissions with their own interests.

We use non-overlapping average monthly submissions as the dependent variable to avoid spurious correlations driven by the high persistence of Libor submissions at higher frequencies. Results are even stronger at the weekly frequency, see Section 8.3. Because of concerns related to the high persistence of Libor submissions, however, we prefer to rely on the monthly data in the main analysis. In addition, many Libor-denominated assets, such as interest rate swaps, are sensitive to Libor measured over a longer period of time.

[9] Because OIS is available only for the *3*-month USD, we proceed as follows. For the *3*-month USD, we use the provided rate. For other maturities and currencies, we assume that the spread between Libor and the OIS rate is the same across all currency-maturity pairs. We construct the OIS rate for a currency-maturity pair as the *3*-month USD OIS rate plus the difference between a given currency-maturity Libor and the *3*-month USD Libor.

The monthly panel predictive regression is:

$$\overline{Submission}_{i,t+1} = a + \lambda^{Libor}\beta_{i,t}^{\Delta Libor} + \lambda^{Sub}\beta_{i,t}^{\Delta Sub} + Controls_t + \textit{Fixed effects} + u_{i,t+1}, \quad (2)$$

where $\overline{Submission}_{i,t+1}$ is the average Libor submission for a panel bank i for a particular currency-maturity pair over the month $t+1$. Variables $\beta_{i,t}^{\Delta Libor}$ and $\beta_{i,t}^{\Delta Sub}$ denote bank-specific estimates for incentives to manipulate Libor for the same currency-maturity pair based on the cash flow and signaling hypotheses from Stage 1 at the end of month t. Because proxies for incentives to manipulate Libor are always estimated using data up to time t, the regression in Eq. (2) is not subject to look-ahead bias.

Libor submissions should reflect the cost at which a panel bank can borrow funds. We therefore add several controls for bank-level risk: the exposures to CDS shocks ($\beta^{\Delta CDS}$), market returns (β^{Mkt}), and changes in *VIX* ($\beta^{\Delta VIX}$) as estimated in Eq. (1). Furthermore, we include as controls the level of a bank's CDS (*CDS*); the logarithm of the bank's market capitalization (*Size*); the domestic 12-month Treasury rate (*Yield*); and the realized volatility, which we compute as the within-month standard deviation of daily equity returns for bank i (*Vol*). All control variables are measured as of month t, and we always include bank and time fixed effects within each currency-maturity pair. Results are robust to the inclusion of other control variables, such as the absolute (or squared) value of sensitivities to changes in Libor and sensitivities to the term spread.

According to our hypotheses, a positive coefficient on the sensitivity to Libor λ^{Libor} is consistent with empirical evidence supporting the cash flow hypothesis. A positive coefficient on the sensitivity to Libor submissions λ^{Sub} is consistent with empirical evidence supporting the signaling hypothesis.

4.3 Banks' gains from manipulation (Stage 3)

We calculate the gains from manipulation in terms of an increase in bank market capitalizations. We describe the details for this calculation for the cash flow hypothesis. Gains due to the signaling hypothesis could be calculated in a similar way.

Note that an attempt to manipulate Libor (Stage 2) may not necessarily affect Libor as calculated by the BBA. To see this, suppose the BBA collects submissions from just two otherwise identical panel banks. Assume also that the two panel banks' Libor exposures are of the exact same size, but of opposite signs. Then, value-maximizing banks that align their submissions with their respective Libor exposures would misreport submissions by the exact same amount, but in opposite directions. Thus, these attempts to manipulate Libor exactly offset each other, leaving Libor unaffected.

To estimate gains from manipulation, while accounting for an offsetting mechanism, we first construct an unmanipulated average monthly submission that each panel bank in our sample would have hypothetically submitted if it had no incentive to manipulate Libor due to the cash flow hypothesis, i.e., if $\beta^{\Delta Libor}$ had been zero. For each panel bank i and for each currency-maturity pair, the predicted average monthly unmanipulated submission $\overline{Submission}^{Unm}_{i,t+1}$ equals:

$$\begin{aligned} \overline{Submission}^{Unm}_{i,t+1} &= \overline{Submission}_{i,t+1} - \lambda^{Libor}\beta^{\Delta Libor}_{i,t} \\ &= a + \lambda^{Sub}\beta^{\Delta Sub}_{i,t} + Controls + \textit{Fixed effects} + u_{i,t+1}. \end{aligned} \tag{3}$$

We then apply the procedure specified by the BBA to these hypothetical average monthly submissions to compute the *unmanipulated* trimmed average Libor ($\overline{Libor}^{Unm}_{t+1}$) for a particular currency-maturity pair. Finally, we compute the *actual* trimmed average monthly Libor from the *actual* average monthly submissions over the same period ($\overline{Libor}_{t+1}$). For the 2 of 20 banks in our sample that are privately held, we assume that $\beta^{\Delta Libor}$ is zero. That is, when calculating unmanipulated Libor, we compute unmanipulated submissions for the public banks and then add back the actual submissions for the private banks.

A comparison of the *unmanipulated* average monthly Libor to the *actual* average monthly Libor allows us to compute the impact of Libor manipulation on the monthly market capitalization of panel banks. That is, the dollar manipulation gain (or loss) for a panel bank i in month $t+1$ for a given currency-maturity pair equals its end-of-month equity market capitalization ($MV_{i,t}$) times $\beta^{\Delta Libor}_{i,t}$ times the difference between the (changes in) *unmanipulated* average monthly Libor and the (changes in) *actual* average monthly Libor. We accumulate manipulation gains for all panel banks across all currency-maturity pairs.

Note that our computed Libor (based on the trimmed means of each bank's average monthly submission) differs slightly from the monthly average of daily Libor. Because we apply the same methodology in calculating *unmanipulated* and *actual* Libor, however, the use of trimmed means of average monthly submission would not introduce a systematic bias, as the effects cancel out.

4.4 Methodology discussion

Our empirical approach is based on testing the relation between the incentives to manipulate Libor and future Libor submissions, where incentives to manipulate Libor are measured as bank equity sensitivities to Libor and Libor submissions. The literature suggests that bank equity sensitivities are informative about interest rate exposures, and we provide corroborating evidence using balance sheet data in Section 7. Still, cash flows accrued from Libor positions may be incorporated slowly in equity prices, and investors may pay limited attention to Libor submissions. Therefore, even a careful estimation of incentives to manipulate Libor from equity returns will be noisy. This has implications for the interpretation of our findings as well as the ability of banks and regulators to learn about Libor manipulation.

Measurement error in the incentives to manipulate Libor would bias our results. This could potentially understate the true effect of Libor manipulation, especially in the main regression without the additional control variables. Indeed, in a panel regression with one independent variable and fixed effects, the slope coefficient and the associated t-statistic are biased toward zero if the measurement error is uncorrelated with the regression error term and the true independent variable. In other regressions, the exact nature of the bias depends on all independent variables, their cross-correlations, and their measurement errors.

Given the noise in measures for incentives to manipulate Libor, we also cannot establish with certainty whether or not a particular bank is attempting to manipulate Libor at any given time. Instead, we focus on average effects. In addition, as econometricians, we have the advantage of analyzing banks' behavior ex-post. It would thus be very difficult to use our approach in real time to establish whether a particular bank is manipulating Libor. This is important because our method relies on publicly available information, and theory predicts that, if investors can identify who the manipulators are, they may stop trading with the manipulating banks (Kumar and Seppi (1992)). This is also why banks have incentives to stay secretive, and we expect them to consider only rather small deviations of Libor submissions from their true borrowing costs.

Note, however, that trading would not necessarily stop even when banks suspect that a counter-party may attempt to manipulate Libor. For example, trading would continue when banks need to trade for liquidity reasons, and there is less of an expected loss from counter party manipulation of Libor than the cost of not trading (having unhedged positions or not being able to fulfill customers' orders). Trading might also continue if counter parties are colluding with private information on other banks' Libor positions. Such private information may stem either from trading with other banks or from conversations with other traders. The informed counter parties may therefore align their positions and submissions when trading with uninformed counter parties (other banks and non-bank traders). Indeed, there is ample anecdotal evidence suggesting that traders and Libor submitters from different banks were coordinating their efforts (Vaughan and Finch (2016)). In our methodology, collusion could happen due to similar Libor exposures.

Finally, given that our estimates are ex-post and based on average effects, it would also be difficult for regulators to use our methodology to provide real-time evidence on which bank is engaged in manipulation and which bank is not. Regulators also have limited resources, both in terms of budget and know-how. They typically focus on the most obvious or promising cases, and might not have noticed Libor manipulations until the accusations surfaced in the popular press. Delayed reaction of regulators may also be caused by conflicts of interest (e.g., banks' representatives were on the board of the BBA), which can explain why, even after the first allegation of Libor manipulation appeared in public, the BBA defended its position that Libor was reliable.

5 Data

We first present the data sources and then discuss the summary statistics.

5.1 Libor and individual bank Libor submissions

We collect daily data for Libor and Libor submissions from Bloomberg from January 2, 2001, through November 28, 2012. Libor is available for 10 currencies and 15 maturities. Wheatley (2012) estimates that the total outstanding notional value of Libor-linked derivatives in 2012 was approximately $300 trillion, with nearly 77% of this volume in interest rate swaps. In Table 1, we reproduce the statistics from Wheatley (2012). Four currencies account for the entire volume of interest rate swaps in June 2012: GBP, JPY, CHF, and USD (see also BIS (2012)). Furthermore, nearly all these swap contracts reference the 1-, 3-, or 6-month Libor. Therefore, we restrict our analysis to these 12 ($= 4 \cdot 3$) currency-maturity pairs.

[Table 1 about here]

For each of these 12 currency-maturity pairs, we collect individual submissions for all panel banks. The panel banks include all banks surveyed by the BBA for determining the daily Libor. The number of panel banks varies with currency from 11 for the CHF to 18 for the USD. The full list of panel banks reporting Libor for each currency, along with the initial date of their submission in our sample, is presented in Internet Appendix Table B.1. Detailed summary statistics for the submissions and corresponding fixings of the 12 currency-maturity pairs are presented in Panel A of Table 2.

[Table 2 about here]

For the most important maturities within each Libor currency as identified in Table 1, namely, the USD *3*-month, GBP *6*-month, JPY *6*-month, and CHF *6*-month, we plot in Figure 1 the average banks' submissions and the two standard deviation cross-sectional bands.

[Figure 1 about here]

Figure 1 reveals that the level of Libor varies substantially across different currencies. The cross-sectional standard deviation of the submissions is low until 2009 and increases steadily thereafter. Therefore, in our Stage 2 regressions, we standardize all dependent and independent variables cross-sectionally within each month and currency-maturity pair. In untabulated results, we find that both the daily panel banks' submissions and Libor are highly persistent, indistinguishable from a unit root. This motivates the use of changes in Libor and bank submissions at weekly frequencies in estimating incentives for manipulating Libor submissions.

5.2 Returns and risk measures

We obtain daily equity returns for the panel banks from Datastream. These are the returns for the entire bank holding company. Thus, our Stage 1 proxy for a panel bank's incentive to manipulate submissions captures total bank Libor exposure, regardless of the subsidiary (commercial bank, investment bank, insurance company) in which the exposure is held. From Datastream, we also obtain daily returns for the aggregate stock market indices for panel bank headquarters, the panel banks' equity market capitalizations, the risk-free rate for each currency-maturity pair, the T-bill rate, and the rate for overnight unsecured lending between banks (overnight indexed swap (OIS) rate).

To compute excess returns, we subtract from equity returns the OIS rate instead of the Treasury bill rate because the T-bill rate was contaminated by a significant flight-to-liquidity component during the financial crisis.[10] The results are robust to using the T-bill rate rather than the OIS rate. We express all returns in US dollars, although we find that keeping equity returns in the local currencies does not impact our results, see Section 8.3.

Our main measures of bank-level risk are the realized volatility of daily bank equity returns and the

[10]The OIS rate is available only from November 26, 2003, onward. To construct an OIS rate before then, we first regress the OIS rate on the Treasury bill rate during 2004. We then use the resulting estimates to construct an artificial OIS rate series for the predicted value January 2001 through November 2003.

bank's 1-year CDS. CDS data come from Datastream and Markit. Panel B of Table 2 provides summary statistics for our control variables.

Finally, note that two out of a total of 20 banks in our sample are privately held, Rabobank and Norinchukin. Because our empirical approach requires data on publicly traded equity, we exclude these two banks from our main analysis. For the purpose of calculating unmanipulated Libor in estimation of gains, we use the actual submissions for these two banks.

5.3 Call report data

To validate our measure of Libor exposure, we also collect bank balance sheet data. The income statement and balance sheet data come from the quarterly Call Reports that the Federal Deposit Insurance Commission requires of all FDIC-insured banks in the US. These data are only available for a subset of banks in our sample that are either incorporated or have significant operations in the US (Bank of America, Citigroup, Deutsche Bank, HSBC, and J. P. Morgan Chase). The data are collected for the full period 2001-2012, with summary statistics reported as in Panel C of Table 2. We defer a detailed discussion until Section 7, where we compare balance sheet data to our proxy for Libor exposures.

6 Results

First we present the summary statistics on our proxies for incentives to manipulate Libor submissions in Stage 1. Then we report results for the hypotheses tests in Stage 2, which relate our proxies for incentives to manipulate to subsequent Libor submissions. Finally, we present results for Stage 3, where we quantify the gains from Libor manipulation.

6.1 Incentives to manipulate Libor (Stage 1)

Table 3 presents summary statistics for sensitivities to changes in Libor $\beta^{\Delta Libor}$ (Panel A) and sensitivities to changes in Libor submissions $\beta^{\Delta Sub}$ (Panel B) from rolling window estimates of Eq. (1). The first rolling window ends on June 30, 2001, and the last on November 28, 2012. The statistics are for the series sampled at the end of each month, separately for each currency-maturity pair. To diminish the effect of outliers, we winsorize the sensitivities at the 1st and 99th percentiles. In untabulated results, we find that our results are robust when we instead trim the sensitivities or leave them uncorrected.

[Table 3 about here]

The cash flow hypothesis does not predict a particular sign for the average $\beta^{\Delta Libor}$. Besides loans and mortgages, panel banks have large derivatives holdings, and Libor exposure on these positions can go in either direction. We indeed find substantial time-series and cross-sectional variation in Libor sensitivities; $\beta^{\Delta Libor}$ is mostly negative but positive for the GBP and the USD 6-month. As expected, most Libor sensitivities are insignificant, but the number of significant coefficients always surpasses the standard statistical probabilities. At the 5% significance level, the fractions of significant estimates range between 0.063 and 0.102; at the 1% significance level, the fractions of significant coefficients are between 0.034 and 0.057. This confirms that our Libor sensitivities are informative, although noisy. The untabulated AR(1) coefficient based on all currencies and maturities is 0.63 at the monthly frequency and declines to 0.26 and -0.08 at the quarterly and semi-annual frequency.[11] Thus, Libor exposures exhibit some persistence, but vary over time considerably.

This is also apparent in Figure 2, Panel A, where we plot the fraction of Libor betas that change sign within a given number of months. We find that 56% of betas change sign within three months, and 95% of betas change sign within a year. These statistics are consistent with our balance sheet estimates reported later in Section 7. In Figure 2, Panel B, we see quite a similar distribution of sign changes, with 43% and 85% of balance sheet Libor exposures changing sign within three and twelve months. Thus, the distribution of our regression estimates is closely aligned with the balance sheet data. Finally, note that correlations of $\beta^{\Delta Libor}$ across different maturities within the same currency are relatively low, ranging between 0.22

[11] Note that the first two coefficients are based on partially overlapping Stage 1 regressions while the semi-annual AR(1) coefficient is based on non-overlapping data.

and 0.77, suggesting that Libor sensitivities vary not only over time and across currencies, but also across different maturities.

[Figure 2 about here]

According to the signaling hypothesis, investors react negatively to high Libor submissions, which would predict an overall negative sign for the average $\beta^{\Delta Sub}$. Our results in Panel B of Table 3 are generally consistent with this prediction. $\beta^{\Delta Sub}$ is negative on average for nine currency-maturity pairs, although it is overall positive for the GBP *3*-month, CHF *3*-month, and CHF *6*-month. Similar to the Libor sensitivities, the number of significant coefficients is higher than implied by the statistical probabilities. At the 5% significance level, the fractions of significant estimates are between 0.060 and 0.096; at the 1% significance level, the fractions of significant coefficients are between 0.028 and 0.051.

6.2 Hypotheses testing (Stage 2)

Our main results are reported in Tables 4 and 5. Each column in the tables reports results for a variation of the regression in Eq. (2). We control for bank and time fixed-effects within each currency-maturity pair. The standard errors are robust to heteroscedasticity and clustered by month. We discuss results for each hypothesis in turn.

[Table 4 about here]

Cash flow hypothesis. We explore the cash flow hypothesis by testing whether the sensitivity to changes in Libor is positively related to future submissions. Starting with a univariate regression in column (1) of Table 4, where we use data for all panel banks over the entire sample, we find that the estimated coefficient on $\beta^{\Delta Libor}$ is indeed positive at 0.025 and significant. Given that the cross-sectional standard deviation of submissions is 2.28 basis points, the estimated coefficient implies that a one-standard deviation increase in the Libor exposure of a panel bank results in a subsequent submission that is higher by 0.071 basis points over the following month. Given that contracts with a notional value of several hundred trillion dollars are pegged to Libor, even a fraction of a basis point can result in large cash flow transfers among investors. The effect is therefore economically important, and we will further quantify it in Section 6.3.

When we include control variables, the extent of the effect is reduced only marginally, from 0.025 in column (1) to 0.023 in column (2), and the estimated coefficient remains significant. The estimated coefficients on the rest of the control variables in column (2) have the expected signs. Especially strong is the positive association between Libor submissions and the level of the CDS. A panel bank's submission also increases with: the bank's exposure to market risk, the bank's exposure to *VIX*, the bank's exposure to shocks in credit risk, and realized volatility, although these coefficients are insignificant.[12] Somewhat mechanically, the submission of a panel bank increases with interest rates. Finally, the submission declines as the size of the bank increases, consistent with the notion that larger banks are seen as safer.

We cannot rule out that some unobservable risk factor drives both $\beta^{\Delta Libor}$ and a panel bank's submission. To the extent that such an unobservable risk factor is bank-specific, however, it would be captured by the bank and time fixed-effects.

Next, we explore whether the effect is more pronounced for currency-maturity pairs with the highest notional value of interest rate derivatives outstanding, where the incentive to manipulate should be strongest as the largest contracts promise the most to be gained. To test this, we estimate a variation of Eq. (2) that interacts $\beta^{\Delta Libor}$ with two dummy variables, *High* and *Low*. Table 1 showed us that USD Libor at a three-month maturity is by far the most important reference rate for interest rate derivatives; more than half of all the interest rate swap contracts and floating-rate notes are tied to this rate. Accordingly, we define the variable *High* as a binary variable that takes a value of one for the USD 3-month Libor, and zero otherwise. The variable *Low* takes a value of one for all the remaining currency-maturity pairs, and zero otherwise.

Results are reported in column (3). The estimated coefficient on $\beta^{\Delta Libor} \times High$ is 0.056, which is almost three times the size of the estimated coefficient on the $\beta^{\Delta Libor} \times Low$ at 0.020. This suggests that manipulation due to cash flow is indeed concentrated in the rate most relevant for interest rate derivatives,

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[12] The Stage 1 coefficients on sensitivity to market risk and VIX are positive on average.

although other currency-maturity pairs are also important; the estimated coefficient on $\beta^{\Delta Libor} \times Low$ is significant (at the 10% level), and it is only slightly lower than the coefficient on $\beta^{\Delta Libor}$ estimated on the full sample in column (1).

All in all, the results provide strong empirical support for the cash flow hypothesis.

Signaling hypothesis. We explore the signaling hypothesis by testing whether the sensitivity to changes in Libor submissions is positively related to future submissions. In a univariate regression in column (4) of Table 4, where we use the data for all panel banks over the entire sample, the estimated coefficient on $\beta^{\Delta Sub}$ is close to zero and insignificant. Also, the estimated coefficient hardly changes and remains insignificant with the addition of $\beta^{\Delta Libor}$ and other control variables, as reported in columns (2) and (5).

We have noted in Section 3 that signaling may be costly to banks. In addition, in a repeated game, investors may twig to the signaling, leaving the strategy ineffective in the long run. Banks would thus use signaling only when it is most beneficial, such as in times of distress, when borrowing costs are generally high, funding liquidity is low, and banks are credit or liquidity constrained. To test this prediction, we interact $\beta^{\Delta Sub}$ with the level of Libor, the *TED* spread, and the bank's CDS. The triple interaction term in Column (6) of Table 4 has a positive coefficient, as expected, at 0.006 and is significant (at the 10% level).[13]

Thus, although we do not detect signaling in the full sample, we do find evidence for signaling in times of distress for the weakest banks, in line with the signaling hypothesis.

[Table 5 about here]

Enforcement and reputation hypothesis. To test how the enforcement actions, begun at the end of 2010, with the threat of legal penalties and potential loss of reputation for the banks, affected Libor manipulation, we examine the evidence for Libor manipulation before 2011 and after 2010. The instrument is a variation of Eq. (2) that interacts incentives to manipulate Libor with two dummy variables, *Pre* and *Post*.

[13]Note that, unlike for $\beta^{\Delta Libor}$, the interaction variables are not dummies; hence, $\beta^{\Delta Sub}$ measures the baseline effect when all other interaction terms are zero and is not directly comparable to the coefficients in the other columns.

The variable *Pre* takes a value of one for the period before 2011, and zero otherwise. The variable *Post* takes a value of one for the period after 2010, and zero otherwise. Our sample ends with the end of 2012, before regulatory changes were made to Libor. We thus do not confound enforcement with regulatory changes.

In order to attribute a reduction in the extent of Libor manipulation to the impact of enforcement actions, other incentives to manipulate Libor should be stable across the two periods. This is a reasonable assumption for the cash flow hypothesis, but it does not hold for the signaling hypothesis. Incentives for signaling are presumably stronger during times of distress for banks such as the *Pre* period, which includes the 2008-2009 crisis. Accordingly, we focus our attention on the cash flow hypothesis. To attribute a decline in Libor manipulation to enforcement actions, we must isolate the effect of regulatory scrutiny from various time trends or changes in the micro and macro environment. In our regressions, we always control for the main variables affecting Libor submissions as well as bank and time fixed-effects within each currency-maturity pair. We are careful in our interpretation of results, though, insofar as our control variables and fixed-effects might not perfectly control for all the differences across the *Pre* and *Post* periods.

Results are reported in Table 5. Column (1) shows that evidence of cash flow manipulation is indeed present only before 2011. The estimated coefficient on the interaction term $\beta^{\Delta Libor} \times Pre$ is 0.033 and significant; the estimated coefficient on $\beta^{\Delta Libor} \times Post$ is close to zero and insignificant. Subject to the caveat discussed above, the evidence is consistent with the view that enforcement actions, with the threat of penalties and loss of reputation, can be effective in deterring fraudulent behavior.

In column (2) of Table 5, we also verify that evidence for the signaling hypothesis is insignificant both before and after 2010. Such an absence of signaling in the *Post* period could also be due to fewer crises for banks in the *Post* period rather than increased enforcement intensity.

To examine whether the effect of enforcement actions varies across banks, we next look at evidence of cash flow manipulation for sanctioned and non-sanctioned banks. We define two additional dummy variables *Sanc* and *Non-Sanc*. *Sanc* takes a value of one for the publicly held panel banks that were among the first to be investigated and that received the largest fines, namely, Deutsche Bank, Union Bank of Switzerland, Royal Bank of Scotland, Societe Generale, and Barclays Bank, and zero otherwise.[14] *Non-Sanc* takes the value one for all the other banks, and zero otherwise. We then interact our new dummies with $\beta^{\Delta Libor} \times Pre$ and $\beta^{\Delta Libor} \times Post$.

Results are reported in columns (3) and (4) of Table 5. In the pre-2011 period, the evidence of manipulation is stronger for the sanctioned banks. The estimated coefficient on $\beta^{\Delta Libor} \times Pre \times Sanc$ is high at 0.059 and significant, while the estimated coefficient on $\beta^{\Delta Libor} \times Pre \times Non - Sanc$ is much smaller at 0.017 and insignificant. After 2010, we find no statistically significant evidence of manipulation for either sanctioned or non-sanctioned banks. These results suggest that the regulators identified and then penalized the banks that contributed to Libor manipulation the most. The fact that there seems to be no Libor manipulation across either sanctioned or non-sanctioned banks in the *Post* period furthermore suggests that regulators established a credible threat of legal penalties and the loss of reputation for all banks.

If we extend the definition of the *Sanc* dummy by including the three remaining banks that received substantially lower fines, namely, Lloyds, J.P. Morgan Chase, and Citigroup, the estimated coefficient on *Sanc* remains significant and higher than the estimated coefficient on *Non-Sanc*, although the difference narrows.

6.3 How much did the panel banks gain from manipulation? (Stage 3)

To measure the extent of the documented manipulation and to better compare the associated costs and benefits, we next estimate the gains from Libor manipulation. Given our empirical evidence that Libor manipulation was present only before 2011 and was driven primarily by banks' incentives to boost profits from their Libor-related positions, all our estimated gains are for the cash flow hypothesis and for the period from July 2001 through December 2010. As detailed in Section 4.3, we compute these gains as the cumulative sum of monthly changes in the market value of banks arising from Libor manipulation.

[14] See footnote 1 for details on the fines. The list excludes Rabobank, which also received a large fine of $1.1 billion, because it is privately held.

The estimated cumulative dollar gains are reported in Table 6. The t-statistics measure the statistical significance of the average monthly gains.

[Table 6 about here]

The total cumulative gains from manipulation for all panel banks and Libor rates from 2001 through 2010 amount to $33.115 billion and are highly significant. Looking at sanctioned and non-sanctioned banks separately, the cumulative gains for the five banks with the largest penalties imposed by the regulators (*Sanc*) are $15.389 billion, compared to $14.125 billion for the other 13 banks.

Because our measure of gains is expressed in terms of the market value of banks and thus measures gains to bank shareholders, it can be compared to penalties, which are also borne by shareholders. For the five banks with the largest fines, the cumulative sum of penalties amounts to $7.8 billion, or approximately half the cumulative gains for the sanctioned banks. These gains, however, stem from manipulation attempts of all banks, and can thus be seen as coming from two sources, namely, from banks' own manipulation attempts and from free-riding on other banks' manipulation attempts. While not all banks can free-ride in equilibrium, it is reasonable to think that banks would weigh the costs of manipulation against the benefits of manipulation that accrue from their own manipulation attempts, rather than the total gains.[15]

We therefore also estimate the gains for sanctioned banks solely from their own manipulation. We proceed as before, except that, to calculate gains for a particular bank, we let this particular bank alone manipulate Libor. As expected, the gain is much lower at $4.150 billion, and exceeded by total penalties. Although gains were realized earlier than penalties and are thus more valuable, these estimates suggest that the penalties alone, not considering the costs related to loss of reputation and civil lawsuits, weigh strongly against the benefits of manipulation.

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[15]We thank an anonymous referee for this insight.

7 Cross-validation of Libor exposure

We cross-validate our proxy for banks' Libor exposure ($\beta^{\Delta Libor}$) using Report of Condition and Income (Call Report) data, required to be filed by all FDIC-insured banks in the US. Besides the banks' interest rate-sensitive assets and liabilities, the Call Reports include detailed information regarding banks' interest rate derivatives portfolios. The data on interest rate derivatives positions are important for our purpose because banks have large trading portfolios that in many cases exceed the size of their loan portfolios. Unfortunately, Call Report data exist only for banks with substantial operations in the US. This restricts our sample to just five panel banks, namely, Bank of America, Citigroup, Deutsche Bank, HSBC, and J. P. Morgan Chase. Of these five banks, information for Deutsche Bank and HSBC covers only their US. subsidiaries and not the entire bank holding company.

From the Call Reports, we collect data on total assets (*TA*), total liabilities (*TL*), total debt (*TD*), notional value of interest rate derivatives used for hedging (*IRDH*) and proprietary trading (*IRDT*), and the net trading income generated by a bank's interest rate derivatives portfolio (*NTI*).

Note that the data do not reference the interest rates of the individual instruments. Because Call Reports cover only banks' US operations and most of the interest rate derivatives are tied to the USD Libor, we assume that all data are referencing USD Libor. This is a strong assumption, but an innocuous one as long as the proportion of interest rate-sensitive holdings related to USD Libor does not vary much over time. The data also do not specify the direction of the exposure of interest rate derivatives held for trading (*IRDT*). To determine the direction of this exposure, we divide the quarterly net trading income generated by a bank's interest rate derivatives portfolio (*NTI*) by the quarterly change in the m-month USD Libor. If this term is positive (negative), we assume that the overall direction of the interest rate trading portfolio in a given quarter is long (short) Libor. We calculate this direction separately for the USD *1*-, *3*-, and *6*-month maturities.

Using these data, we define a bank's quarterly balance sheet exposure (*BSE*) to USD Libor in a given quarter and maturity m as the ratio of a bank's net interest rate exposure over its total assets:

$$BSE_m = \frac{TA - \left(TL + TD + IRDH + IRDT \times \text{sign}\left[\frac{NTI}{\Delta Libor_m}\right]\right)}{TA}. \tag{4}$$

Panel C of Table 2 reported summary statistics for these balance sheet variables from the Call Report data and also the resulting quarterly balance sheet USD Libor exposure (*BSE*) using Eq. (4). The off-balance sheet derivatives for the banks in our sample far exceed the total balance sheet assets. This confirms that data on derivatives positions are necessary to capture banks' net exposure to interest rate movements. The ratio of a bank's net interest rate exposure over its total assets (*BSE*) is on average 1.33 for *1*-month maturity, -0.22 for *3*-month, and 0.84 for *6*-month, with a standard deviation of 18. This indicates that banks were not always long or short Libor, but their exposures often changed sign over the sample period. Finally, the average AR(1) across BSE measures at the quarterly frequency is 0.10, which is comparable to the persistence of our Stage 1 estimate for Libor exposure.

We explore the relation between Libor exposures obtained from our Stage 1 regression and from Call Report data by running a regression for each USD Libor maturity m pooled across all five banks:

$$\overline{\beta}^{\Delta Libor}_{m,t} = \alpha_m + \delta_m BSE_{m,t} + \varepsilon_t, \tag{5}$$

where $\overline{\beta}^{\Delta Libor}_{m,t}$ denotes the average USD Libor exposure from Eq. (1) over quarter t, and $BSE_{m,t}$ is the balance sheet exposure at the end of quarter t. The results are robust to using $\beta^{\Delta Libor}_{m,t}$ measured over the last week of quarter t rather than averaged over the whole quarter t.

The results are reported in Table 7. Columns (1) through (3) present results for the *1*, *3*, and *6*-month maturities. In column (4), the left-hand side and the right-hand side variables in Eq. (5) are averaged across the maturities. The coefficients are multiplied by 100 and expressed in percentages.

[Table 7 about here]

Our proxy for Libor exposure $(\beta^{\Delta Libor})$ correlates positively with the exposure estimated from the Call

Reports. The estimated coefficient on balance sheet exposure *BSE* for different maturities is always positive and significant, except at the *1*-month maturity. The highest R^2 of 0.053 is observed for the *3*-month maturity, which corresponds to an implied correlation of approximately 0.24. For the average specification in column (4), the R^2 is 0.028, which corresponds to an implied correlation of nearly 0.17. These results suggest that our proxy for Libor exposure incorporates information similar to the measure of interest rate exposure estimated from balance sheet data.

8 Robustness

We conduct several robustness checks. We first address the potential concern that our results are driven by differences in banks' general interest rate risk exposures. Then, we address potential endogeneity issues in the estimation of Libor sensitivities. Finally, we report other robustness checks with respect to our modelling choices. Results reported in Table 8 correspond to our main results for the enforcement and reputation hypothesis reported in column (1) of Table 5. We focus on the significance of the estimated coefficient for $\beta^{\Delta Libor}\times$ *Pre*.

[Table 8 about here]

8.1 Interest rate risk

One potential concern is that Libor is highly correlated with other short-term interest rates, and our measure of Libor exposure is a general measure of the interest rate risk, i.e., a duration measure. This could give rise to an alternative explanation for our results: that the positive association between banks' exposures to Libor and their subsequent submissions occurs simply because banks set higher submissions in response to increased interest rate risk. To address this concern, we provide three additional sets of tests.

First, note that interest rate risk (duration) depends on the degree of the interest rate exposure rather than its sign. Then, according to the interest rate risk explanation, Libor submissions should be positively related to the degree of the Libor exposure and not to the signed value of the Libor exposure, which we use in our main analysis. We thus repeat our main tests by adding either the absolute value or the squared value of banks' Libor exposures as new control variables. Results are reported in Table 8, Panel A, columns (1) and (2). The estimated coefficients on the new variables are close to zero and insignificant. In the meantime, the main coefficient on the signed Libor exposure remains largely unaffected.

Second, instead of using changes in Libor, we experiment with two alternative measures of Libor shocks. These are constructed as the residuals from either an AR(1) model or an AR(1) model augmented by the term spread. Results are reported in Panel A, columns (3) and (4). In both cases, the estimates mimic very closely the primary result in Table 5, column (1).

Finally, to account for other sources of interest rate risk, we include the term spread in Eq. (1). We then repeat the main tests while adding the estimated coefficient for changes in the term spread from Eq. (1) as an additional control variable. In Panel A, column (5), the estimated coefficient for sensitivity to the term spread is insignificant, and our main coefficient even increases. All in all, these tests suggest that our results are not driven by differences in banks' interest rate risk exposures.

8.2 Endogeneity

Our measure of Libor sensitivity in the primary analysis is the estimated coefficient $\beta^{\Delta Libor}$ in the regression in Eq. (1). Because our subsequent analysis suggests that Libor is manipulated, our proxy for Libor exposure may be endogenous and hence biased. That is, if all panel banks manipulate Libor in the direction of their interest rate exposure, then Libor is a function of the average Libor exposure. This in turn may lead to spurious results.

To address this concern, we estimate our Libor exposures using an instrumental variable (IV) approach. To enhance identification, all aggregate Stage 1 variables that may capture Libor news and that are exogenous to manipulation should be included in the IV estimation. Therefore, we use as instruments the risk-free rate that corresponds to Libor in currency and maturity, the market excess returns, and changes in *VIX*.

We implement our instrumental variable approach using the standard two-stage least-squares approach. In Stage 1, we regress changes in Libor for each currency-maturity pair on the corresponding instruments.

Next, we replace the changes in Libor in Eq. (1) with the fitted value from the Stage 1 regression. As in the main analysis, we use a rolling window approach. To validate our instrumental variable approach, we apply the standard F-test for overidentifying restrictions.

The Stage 1 estimates and the corresponding F-tests are tabulated in Table B.2 of the Internet Appendix. The F-tests are strongly rejected across all currencies and maturities, validating our instruments. Of our three instruments, the risk-free rate is by far the most important variable, while the other two variables are insignificant. Therefore, as a further check, we re-run our IV estimation using only the risk-free rate as an instrument. The untabulated results remain very similar.

Stage 2 results based on instrumented Libor exposures are reported in Panel A, column (6), of Table 8. Our main coefficient on $\beta^{\Delta Libor} \times$ *Pre* declines somewhat, yet remains statistically significant and economically important. Indeed, we would expect those Stage 2 coefficients to be lower than in the primary tests. To see this point, note that the sign of the bias depends on the stochastic properties of the exposures to true Libor. As average bank sensitivities are highly persistent (see results in Section 6.1), it follows in our model that the Stage 1 estimator is biased toward zero, and hence the Stage 2 estimate is biased upward. Overall, our conclusions appear to be robust to endogeneity concerns.

8.3 Other robustness analysis

We also analyze the sensitivity of our results to other modelling choices. Our primary analysis estimates proxies for incentives to manipulate Libor using 26-week rolling windows, see Eq. (1). To analyze how sensitive results are to the length of the window, we now vary the window size from 20 to 45 weeks in steps of 5 weeks, and report results for each window length in Panel B of Table 8. The estimated coefficient on $\beta^{\Delta Libor} \times$ *Pre* is always significant and displays a hump-shaped pattern in the length of the window. It first increases from 0.024 for the 20-week window size to 0.032 for the 25-week window, then falls to 0.027 for the 30-week window, and remains relatively stable until the 45-week window. This pattern is consistent with the trade-off between the statistical uncertainty of coefficients measured over shorter windows and the staleness of estimated coefficients measured over longer windows. Note also that the estimated coefficient on $\beta^{\Delta Libor} \times$ *Post* is always insignificant, in line with our hypothesis. We thus conclude that our results are robust to a wide range of window sizes.

Second, because of the high persistence of Libor submissions, we test our hypotheses in the primary analysis by relating proxies for incentives to manipulate Libor to (non-overlapping) average submissions over the month following. Now, we repeat the analysis using (non-overlapping) average submissions over the next week instead of month. As reported in Table 8, Panel C, column (1), our main coefficient declines slightly, but is statistically stronger than in the main analysis.

Third, we assess the robustness of our results to estimating Libor sensitivities separately for each currency-maturity pair. We restrict the analysis to the set of five currency-maturity pairs with the highest notional value, namely USD *1*-month, USD *3*-month, GBP *6*-month, JPY *6*-month, and CHF *6*-month. We know from Table 1 that these pairs account for more than 92% of the overall Libor volume, and hence they should be the most informative. We then estimate our Stage 1 regression using all currency-maturity pairs on which a given bank is reporting. To keep the model parsimonious, we do not include variables for signaling, as these are found to be insignificant over the full sample. The results are reported in column (2) of Panel C. Notwithstanding the increased noise due to added regressors and reduced sample size, we still find a positive coefficient on $\beta^{\Delta Libor}$ in the Pre-period at 0.025, with a t-statistic of 1.893, and an insignificant negative estimate in the Post-period.

Fourth, in the primary analysis, the pre-period (variable Pre) ends in December 2010. Now, we vary the length of the pre-period by three months and present results for the pre-period ending in September 2010 and March 2011. As reported in Panel C, columns (3) and (4), the estimated coefficients are almost identical to the initial specification.

Fifth, in the primary analysis, we use returns denominated in USD. In Panel C, column (5), we present results when the panel banks' equity and market returns are denominated in the currency of the countries of incorporation of the panel banks. The main results remain largely unchanged.

9 Conclusion

Recent banking scandals have called into question the integrity of financial markets and opened up a discussion about the role of regulation and enforcement. We contribute to this discussion by examining the extent of Libor manipulation through the lens of a cost-benefit analysis. Using a large cross-section of banks' Libor submissions, from which Libor is computed, from 2001 through 2012, we first document evidence consistent with manipulation of Libor so banks could profit from positions tied to the value of Libor. We also find some evidence that banks tried to signal higher quality through low Libor submissions in times of distress. Most intriguingly, Libor manipulation seems to have ceased after regulators started investigating the alleged manipulations in 2010-2011 and the public became aware of the investigations. Regulators also seem to be quite adept at catching manipulators, as the evidence of manipulation before 2011 is stronger for sanctioned than for non-sanctioned banks. Overall, our results are consistent with a view that enforcement actions and a credible threat of large penalties could discourage manipulation.

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Table 1: Libor as a reference rate

This table reports the notional value for interest rate swap contracts and floating-rate notes referenced to Libor for different currencies and maturities as a percentage of the size of the total market. The data are from Dealogic and the Depositary Trust and Clearing Corporation. The table is adapted from Wheatley (2012, Table 5.A, p. 36). The last row and column report notional value as a percentage of the size of the total market for each maturity and currency, respectively.

	1m	3m	6m	12m	**Total**
USD	5.6%	52.8%	0.3%	0.1%	59%
EUR	-	-	0.1%	-	0%
GBP	0.4%	2.9%	8.9%	-	12%
JPY	0.1%	3.6%	23.5%	-	27%
CHF	0.1%	0.4%	1.6%	-	2%
AUD	-	-	-	-	0%
CAD	-	-	-	-	0%
NZD	-	-	-	-	0%
SEK	-	-	-	-	0%
DKK	-	-	-	-	0%
Total	6%	60%	34%	0%	100%

Table 2: Summary statistics

This table reports summary statistics for the data used in the main analysis. Panel A shows weekly Libor bank submissions and Libor fixings across the 12 currency-maturity pairs. N is the number of (panel or time-series) observations. Panel B shows weekly equity returns (r), banks' log market capitalization (*Size*), 1-year domestic Treasury rate (*Yield*), realized volatility of banks' equity returns (*vol*), 1-year CDS premium on banks' equity in bps (*CDS*), domestic aggregate stock market returns (r_{Mkt}), and changes in VIX (ΔVIX). Panel C shows balance sheet variables from quarterly Call Report data for five banks with significant operations in the U.S. (Bank of America, Citigroup, Deutsche Bank, HSBC, and JP Morgan Chase). *TA* is total assets, *TL* is total liabilities, *TD* is total debt, *IRDH* is the notional value of interest rate derivatives used for hedging, and *IRDT* is the notional value of interest rate derivatives used for trading (expressed in USD millions). BSE_{1m}, BSE_{3m}, and BSE_{6m} are bank balance sheet Libor exposures for the 1-, 3-, and 6-month maturity USD Libor according to Eq. (4). The sample period is from 2001 to 2012.

Panel A: Libor

	Submissions					Fixings				
	N	mean	sd	min	max	N	mean	sd	min	max
USD-1m	7,127	1.899	0.023	0.110	5.850	570	2.006	1.830	0.185	5.819
USD-3m	7,127	2.034	0.025	0.200	5.800	570	2.139	1.809	0.245	5.720
USD-6m	7,127	2.190	0.029	0.300	5.630	570	2.291	1.746	0.383	5.618
GBP-1m	7,007	3.055	0.023	0.410	6.800	570	3.242	2.034	0.496	6.750
GBP-3m	7,007	3.220	0.027	0.450	6.930	570	3.401	1.991	0.523	6.903
GBP-6m	7,007	3.365	0.029	0.550	6.810	570	3.536	1.901	0.680	6.793
JPY-1m	6,517	0.242	0.020	-0.060	1.350	570	0.232	0.251	0.036	1.060
JPY-3m	6,594	0.315	0.023	-0.060	1.350	570	0.305	0.302	0.046	1.094
JPY-6m	6,594	0.405	0.025	-0.020	1.430	570	0.391	0.328	0.059	1.185
CHF-1m	6,235	0.825	0.019	-0.250	3.500	570	0.819	0.858	-0.013	3.002
CHF-3m	5,690	0.934	0.021	-0.150	3.500	570	0.930	0.922	0.005	3.098
CHF-6m	5,690	1.029	0.029	0.030	3.500	570	1.023	0.934	0.047	3.171

Panel B: Returns and control variables

	N	mean	sd	min	max
r	9,542	0.002	0.068	-0.717	1.332
Size	9,542	11.062	0.658	8.584	12.532
Yield	9,542	2.107	1.776	-0.477	6.514
Vol	9,542	0.022	0.020	0.001	0.369
CDS	9,542	49.947	73.424	0.842	971.629
r_{Mkt}	570	0.002	0.027	-0.142	0.095
ΔVIX	570	21.504	9.757	9.890	74.260

Panel C: Balance sheet variables

	N	mean	sd	min	max
TA	149	$ 1,170.71	$ 781.40	$ 52.08	$ 2,370.59
TL	149	$ 222.30	$ 169.71	$ 0.09	$ 549.80
TD	149	$ 68.58	$ 56.83	$ 0.00	$ 249.86
$IRDH$	149	$ 24.55	$ 31.34	$ 0.01	$ 208.07
$IRDT$	149	$ 21,960.82	$ 21,227.33	$ 9.76	$ 70,210.59
BSE_{1m}	149	1.326	17.586	-41.350	43.990
BSE_{3m}	149	-0.220	17.521	-43.540	49.970
BSE_{6m}	149	0.840	17.596	-41.350	43.990

Table 3: Summary statistics for incentives to manipulate Libor submissions (Stage 1)

This table reports summary statistics for incentives to manipulate Libor submissions due to the cash flow hypothesis in Panel A (sensitivities to changes in Libor: $\beta^{\Delta Libor}$) and incentives to manipulate Libor submissions due to the signaling hypothesis in Panel B (sensitivities to changes in Libor submissions: $\beta^{\Delta Sub}$). The sensitivities are obtained by estimating the regression in Eq. (1). Results are presented separately for four Libor currencies (USD, GBP, JPY, and CHF) and three maturities (1-, 3-, and 6-month). All sensitivities are estimated using 26-week rolling windows. The first rolling window ends on June 30, 2001, and the last on November 28, 2012. The estimates are sampled monthly and are winsorized at the 1st and 99th percentile. In addition to the standard statistics, we report the fractions of significant coefficients at the 10%, 5%, and 1% levels and the within-currency correlations.

Panel A: $\beta^{\Delta Libor}$

Currency-maturity	N	mean	sd	min	max	Fract. 10%	Fract. 5%	Fract. 1%	corr(1m)	corr(3m)	corr(6m)
USD-1m	1,473	-0.074	1.329	-12.740	8.388	12.20%	7.81%	4.01%	1		
USD-3m	1,473	-0.053	0.918	-19.770	4.489	15.90%	9.98%	5.70%	0.483	1	
USD-6m	1,473	0.017	0.606	-7.106	3.358	16.90%	10.20%	5.57%	0.414	0.470	1
GBP-1m	1,486	0.129	1.250	-9.739	9.618	13.40%	7.67%	4.10%	1		
GBP-3m	1,486	0.014	0.669	-5.558	5.275	13.50%	7.67%	4.31%	0.506	1	
GBP-6m	1,486	0.041	0.542	-4.466	4.845	12.10%	8.14%	4.04%	0.406	0.769	1
JPY-1m	1,440	-0.123	5.324	-60.770	41.360	11.50%	6.32%	3.40%	1		
JPY-3m	1,445	-0.298	5.620	-53.610	33.190	12.90%	7.68%	4.15%	0.259	1	
JPY-6m	1,445	-0.832	10.570	-157.600	53.660	13.40%	7.68%	3.60%	0.215	0.649	1
CHF-1m	1,402	-0.079	1.136	-11.030	10.630	13.30%	8.70%	5.06%	1		
CHF-3m	1,290	-0.021	1.077	-9.787	5.466	14.30%	8.84%	5.66%	0.644	1	
CHF-6m	1,290	-0.009	0.934	-8.934	7.128	16.20%	8.99%	4.57%	0.378	0.570	1

Panel B: $\beta^{\Delta Sub}$

Currency-maturity	N	mean	sd	min	max	Fract. 10%	Fract. 5%	Fract. 1%	corr(1m)	corr(3m)	corr(6m)
USD-1m	1,473	-0.008	0.442	-1.687	2.751	13.40%	8.69%	4.01%	1		
USD-3m	1,473	-0.002	0.538	-3.104	7.536	13.40%	7.54%	3.46%	0.675	1	
USD-6m	1,473	-0.014	0.468	-2.948	2.483	15.80%	9.50%	4.96%	0.621	0.637	1
GBP-1m	1,486	-0.004	0.409	-1.942	5.666	13.80%	8.41%	4.58%	1		
GBP-3m	1,486	0.008	0.380	-1.320	5.129	13.90%	8.34%	4.37%	0.697	1	
GBP-6m	1,486	-0.001	0.375	-1.597	3.718	14.90%	9.56%	5.05%	0.612	0.807	1
JPY-1m	1,440	-0.029	0.454	-1.959	4.573	13.60%	8.13%	3.89%	1		
JPY-3m	1,445	-0.046	0.403	-2.228	1.859	12.50%	6.78%	3.18%	0.700	1	
JPY-6m	1,445	-0.030	0.383	-1.555	1.602	12.50%	6.71%	3.11%	0.647	0.844	1
CHF-1m	1,402	-0.010	0.349	-2.020	1.784	10.80%	5.99%	3.57%	1		
CHF-3m	1,290	0.000	0.341	-1.461	1.753	13.20%	7.52%	2.79%	0.774	1	
CHF-6m	1,290	0.006	0.338	-1.811	2.308	12.60%	6.43%	3.10%	0.675	0.781	1

Table 4: Testing the cash flow and signaling hypotheses

This table reports results for the cash flow and signaling hypotheses. Each column refers to a variation of Eq. (2), which regresses monthly average bank Libor submissions on lagged sensitivities to Libor ($\beta^{\Delta Libor}$), lagged sensitivities to Libor submissions ($\beta^{\Delta Sub}$), interaction terms, and control variables. The regression is estimated by pooling observations for panel banks across four currencies (USD, GBP, JPY, and CHF) and three maturities (1-, 3-, and 6-month). *High* is defined as one for the 3-month USD Libor, and zero otherwise. *Low* is defined as 1 - *High*. TED is the TED spread, defined as Libor minus OIS. Control variables include: the sensitivities of bank excess returns to the domestic market excess returns (β^{Mkt}), changes in VIX ($\beta^{\Delta VIX}$), and changes in CDS in excess of the average CDS ($\beta^{\Delta CDS}$); the level of banks' CDS; banks' log market capitalization (*Size*); the one-year yield of the domestic country (*Yield*); and banks' realized stock return volatility (*Vol*). All variables are cross-sectionally standardized. All regressions include bank and time fixed-effects within each currency-maturity pair. In parentheses below the estimated coefficients are the t-statistics based on robust standard errors clustered by month. Statistical significance at the 1%, 5%, and 10% level is denoted by three, two, and one asterisks, respectively. The R^2 is from regression of the residuals of the dependent and independent variables on the fixed effects. The data represent monthly observations from July 2001 through November 2012.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
$\beta^{\Delta Libor}$	0.025**	0.023**			0.027**	0.022*
	(2.317)	(2.068)			(2.385)	(1.957)
$\beta^{\Delta Sub}$		0.001	0.002	0.007	0.012	0.070*
		(0.133)	(0.212)	(0.701)	(1.110)	(1.782)
$\beta^{\Delta Libor} \times High$			0.056**			
			(2.058)			
$\beta^{\Delta Libor} \times Low$			0.020*			
			(1.783)			
$\beta^{\Delta Sub} \times CDS$						-0.015
						(-1.124)
$\beta^{\Delta Sub} \times Libor$						-0.009
						(-0.657)
$\beta^{\Delta Sub} \times TED$						0.012
						(0.135)
$\beta^{\Delta Sub} \times TED \times CDS$						-0.042
						(-1.598)
$\beta^{\Delta Sub} \times Libor \times CDS$						0.000
						(0.073)
$\beta^{\Delta Sub} \times TED \times Libor \times CDS$						0.006*
						(1.828)
β^{Mkt}		0.020	0.019			0.021
		(1.145)	(1.138)			(1.258)
$\beta^{\Delta VIX}$		0.018	0.018			0.018
		(1.472)	(1.441)			(1.506)
$\beta^{\Delta CDS}$		0.018	0.018			0.018
		(1.413)	(1.414)			(1.453)
CDS		0.096***	0.096***			0.100***
		(7.422)	(7.396)			(7.729)
$Size$		-0.131***	-0.131***			-0.131***
		(-5.181)	(-5.184)			(-5.198)
$Yield$		0.111***	0.111***			0.117***
		(3.852)	(3.856)			(4.071)
Vol		0.015	0.015			0.014
		(1.073)	(1.072)			(1.011)
Obs.	17,078	17,078	17,078	17,078	17,078	17,078
R^2	0.001	0.031	0.031	0.000	0.001	0.034

Table 5: Testing the enforcement and reputation hypothesis

This table reports results for the enforcement and reputation hypothesis. Each column refers to a variation of Eq. (2), which regresses monthly average bank Libor submissions on lagged sensitivities to Libor ($\beta^{\Delta Libor}$), lagged sensitivities to Libor submissions ($\beta^{\Delta Sub}$), interaction terms, and control variables. The regression is estimated by pooling observations for panel banks across four currencies (USD, GBP, JPY, and CHF) and three maturities (1-, 3-, and 6-month). *Pre* is defined as one for the period before 2011, and zero otherwise. *Post* is defined as 1 - *Pre*. *Sanc* is defined as one for the five panel banks that have been among the first to be investigated and also received the largest fines, and zero otherwise. *Non-Sanc* is defined as 1 - *Sanc*. Control variables are defined as in Table 4. All variables are cross-sectionally standardized. All regressions include bank and time fixed-effects within each currency-maturity pair. In parentheses below the estimated coefficients are the t-statistics based on robust standard errors clustered by month. Statistical significance at the 1%, 5%, and 10% level is denoted by three, two, and one asterisks, respectively. The R^2 is from regression of the residuals of the dependent and independent variables on the fixed effects. The data represent monthly observations from July 2001 through November 2012.

Variable	(1)	(2)	(3)	(4)
$\beta^{\Delta Libor} \times Pre$	0.033***	0.033***		0.033***
	(2.724)	(2.729)		(2.725)
$\beta^{\Delta Libor} \times Post$	-0.017	-0.018	-0.017	
	(-0.685)	(-0.696)	(-0.680)	
$\beta^{\Delta Sub}$	0.002		0.003	0.002
	(0.165)		(0.259)	(0.163)
$\beta^{\Delta Sub} \times Pre$		0.004		
		(0.311)		
$\beta^{\Delta Sub} \times Post$		-0.006		
		(-0.371)		
$\beta^{\Delta Libor} \times Pre \times Sanc$			0.059***	
			(3.044)	
$\beta^{\Delta Libor} \times Pre \times Non\text{-}Sanc$			0.017	
			(1.338)	
$\beta^{\Delta Libor} \times Post \times Sanc$				-0.034
				(-0.923)
$\beta^{\Delta Libor} \times Post \times Non\text{-}Sanc$				-0.003
				(-0.162)
β^{Mkt}	0.019	0.019	0.019	0.019
	(1.125)	(1.119)	(1.127)	(1.108)
$\beta^{\Delta VIX}$	0.019	0.019	0.019	0.019
	(1.574)	(1.603)	(1.578)	(1.562)
$\beta^{\Delta CDS}$	0.018	0.018	0.019	0.018
	(1.405)	(1.419)	(1.476)	(1.424)
CDS	0.096***	0.096***	0.096***	0.096***
	(7.447)	(7.434)	(7.448)	(7.366)
$Size$	-0.131***	-0.131***	-0.129***	-0.132***
	(-5.215)	(-5.202)	(-5.095)	(-5.238)
$Yield$	0.111***	0.111***	0.113***	0.112***
	(3.894)	(3.887)	(3.938)	(3.899)
Vol	0.015	0.015	0.016	0.015
	(1.108)	(1.105)	(1.162)	(1.098)
Obs.	17,078	17,078	17,078	17,078
R^2	0.032	0.032	0.032	0.032

Table 6: Estimated gains from Libor manipulation

This table reports estimated gains from Libor manipulation under the cash flow hypothesis for the period January 2, 2001, to December 31, 2010. Gains for each bank are computed in terms of market value of banks, using the procedure outlined in Section 4.3. Total gains is the sum of gains across all banks. *Sanc* is defined as one for the five panel banks that were among the first to be investigated and that received the largest fines, and zero otherwise. *Non-Sanc* is defined as 1 - *Sanc*. Below the estimates are the t-statistics based on the statistical significance of average monthly gains. Statistical significance at the 1%, 5%, and 10% level is denoted by three, two, and one asterisks, respectively. Units are USD millions.

	(1)	(2)
Total gains	$33,115***	
	(6.634)	
$Sanc$		$15,389***
		(5.446)
$Non\text{-}Sanc$		$14,125***
		(6.296)

Table 7: Balance sheet and Libor exposure

This table reports results for Eq. (5), which regresses quarterly sensitivity of bank excess returns to changes in Libor ($\beta^{\Delta Libor}$) on Libor exposure computed from Call Report balance sheet data (*BSE*). The regression is estimated by pooling observations for five banks with substantial operations in the U.S. covered by the Call Reports data. The *BSE* is computed at the end of each quarter according to Eq. (4), and $\beta^{\Delta Libor}$ is the quarterly average of weekly observations from the regression in Eq. (1). All Libor exposures are for the USD Libor. Columns (1) through (3) present results for the 1, 3, and 6-month maturity. In column (4), both measures of Libor exposure are averaged across the maturities. The coefficients are multiplied by 100 and expressed in percentages. The t-statistics in parentheses are clustered by quarter. Statistical significance at the 1%, 5%, and 10% level is denoted by three, two, and one asterisks, respectively.

	(1) 1m	(2) 3m	(3) 6m	(4) Average
BSE	0.268	0.750***	0.510***	0.575**
	(1.568)	(2.878)	(2.777)	(2.050)
R^2	0.002	0.053	0.050	0.028

Table 8: Robustness analysis

This table reports various specifications of results for the enforcement and reputation hypothesis corresponding to column (1) in Table 5. Panel A reports in columns (1) and (2) the absolute value and the squared value of $\beta^{\Delta Libor}$ as additional control variables. In columns (3) and (4), changes in Libor are replaced by residuals from an AR(1) model or an AR(1) model augmented by the term spread. Column (5) adds the sensitivity to the term spread, estimated as an additional regressor in the Stage 1 regression. Column (6), changes in Libor in Stage 1 are instrumented with changes in the corresponding risk-free rate, market excess returns, and changes in VIX. Panel B reports Stage 1 sensitivities estimated on rolling windows from 20 to 45 weeks in steps of 5 weeks. Panel C reports results for other robustness analyses: in column (1), results are based on weekly data; in column (2), the Stage 1 regression includes only changes in Libor to the five main currency-maturity pairs; in columns (3) and (4), *Pre* is defined as one for the period through September 2010 and through March 2011, and zero otherwise; and in column (5), the Stage 1 sensitivities are estimated using local currency-denominated returns. All regressions include bank and time fixed effects within each currency-maturity pair and the following untabulated controls: $\beta^{\Delta Sub}$, β^{Mkt}, $\beta^{\Delta CDS}$, $\beta^{\Delta VIX}$, *CDS*, *Size*, *Yield*, and *Vol*. The t-statistics in parentheses are based on robust standard errors clustered by month. Statistical significance at the 1%, 5%, and 10% level is denoted by three, two, and one asterisks, respectively. The R^2 is from the regression of the residuals of the dependent and independent variables on the fixed effects. The data represent monthly observations from July 2001 through November 2012.

Panel A: Interest rate risk and endogeneity

Variable	(1) $\lvert\beta^{\Delta Libor}\rvert$	(2) $(\beta^{\Delta Libor})^2$	(3) AR(1)	(4) AR(1) + TSPR	(5) TSPR	(6) TSLS
$\beta^{\Delta Libor} \times Pre$	0.033***	0.033***	0.032***	0.030**	0.040***	0.017**
	(2.731)	(2.730)	(2.688)	(2.468)	(3.403)	(1.980)
$\beta^{\Delta Libor} \times Post$	-0.017	-0.017	-0.018	-0.019	-0.025	-0.001
	(-0.674)	(-0.681)	(-0.712)	(-0.793)	(-1.009)	(-0.056)
$\lvert\beta^{\Delta Libor}\rvert$	-0.010					
	(-0.726)					
$(\beta^{\Delta Libor})^2$		-0.004				
		(-0.776)				
$\beta^{\Delta TSPR}$					-0.011	
					(-0.919)	
Obs.	17,078	17,078	17,078	17,078	17,078	16,928
R^2	0.032	0.032	0.032	0.032	0.033	0.032

Panel B: Length of the rolling window (Stage 1, in weeks)

Variable	20	25	30	35	40	45
$\beta^{\Delta Libor} \times Pre$	0.024*	0.032***	0.027**	0.028**	0.025**	0.027**
	(1.954)	(2.657)	(2.266)	(2.343)	(2.019)	(2.085)
$\beta^{\Delta Libor} \times Post$	-0.011	-0.016	-0.018	-0.018	-0.009	0.009
	(-0.456)	(-0.657)	(-0.884)	(-0.926)	(-0.452)	(0.418)
Obs.	17,256	17,108	16,987	16,804	16,633	16,456
R^2	0.030	0.032	0.032	0.033	0.035	0.037

Panel C: Other robustness analysis

Variable	(1) Weekly	(2) Main pairs	(3) Pre Sep2010	(4) Pre Mar2011	(5) Local currency
$\beta^{\Delta Libor} \times Pre$	0.026***	0.025*	0.039***	0.033***	0.029**
	(4.373)	(1.893)	(3.379)	(2.842)	(2.479)
$\beta^{\Delta Libor} \times Post$	-0.016	-0.013	-0.031	-0.025	-0.032
	(-1.293)	(-0.517)	(-1.206)	(-0.990)	(-1.358)
Obs.	74,597	6,182	17,078	17,078	17,078
R^2	0.039	0.038	0.032	0.032	0.031

Figure 1: Time-series of Libor submissions

This figure plots weekly averages of panel banks' Libor submissions (solid line) with two standard deviation cross-sectional bands (dotted lines) for the four Libor rates: USD-3 month (Panel A), GBP-6 month (Panel B), JPY-6 month (Panel C), and CHF-6 month (Panel D). The sample contains weekly observations from January 2, 2001, through November 28, 2012.

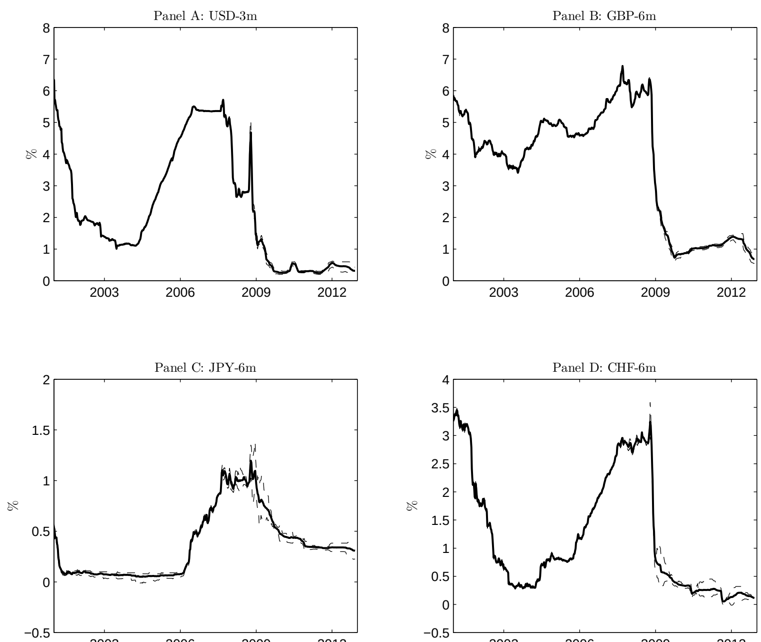
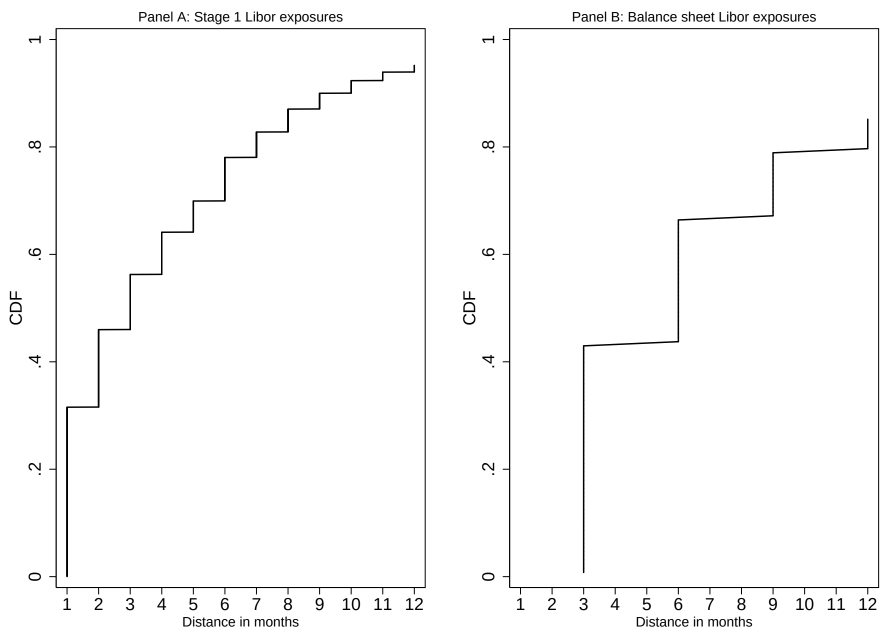


Figure 2: Cumulative distribution function (CDF) of sign change in Libor exposures

Panel A shows the fraction of Libor exposures from the Stage 1 regression that change sign within a given number of months. Panel B shows the analogous distribution based on the Call Report data (see Section 7).



Internet Appendix

A Further details on Libor computation

This internet appendix provides details on the Libor computation in place throughout the period of our analysis, 2001 through 2012. During the period, the organization responsible for the computation was the British Bankers' Association (BBA), a trade association of over 200 banks based in London. The actual collection of the data and the computation of Libor were performed by Thomson Reuters. Libor is computed for 10 distinct currencies (the Australian dollar, the British pound sterling, the Canadian dollar, the Danish krone, the Euro, the Japanese yen, the New Zealand dollar, the Swedish krona, the Swiss franc, and the U.S. dollar) and 15 different maturities. The 15 maturities range from overnight to one year.

While any bank that trades in London can apply to become a panel bank for any currency for which Libor is computed, its selection by BBA is based on three factors: (i) the bank's scale of market activity, (ii) its reputation, and (iii) its perceived expertise. Thus, the number of panel banks varies with currencies and over time, but within a given currency, the number does not vary across maturities.

Interest rate data from the panel banks are collected via a survey. Panel banks are supposed to report the lowest perceived interest rate at which the bank can borrow an unsecured, ”reasonable loan amount” in the London interbank market for a given currency and maturity. The maturity dates are standardized to International Swap Dealers Association (ISDA) norms. The BBA does not define a ”reasonable loan amount.”

Libor submissions are supposed to be reported by the bank's staff primarily responsible for its cash or liquidity management, via a secure computer application, to Thomson Reuters by 11:10am, London time. Thomson Reuters checks for data errors, allows the panel banks to correct obvious mistakes, and publishes Libor by 11:30am. At the same time, Thomson Reuters also publicly releases the individual submissions provided by all the panel banks. If any errors are identified post-publication, Thomson Reuters corrects these and publishes recomputed Libor and individual submissions by 12:00 noon, London time. Panel banks do not have access to individual submissions and cannot legally view other panel banks' submissions prior to publication of the official Libor.

For computing the trimmed averages, the number of contributing banks is rounded down to the nearest number divisible by four. For example, for the USD with 18 panel banks the number of banks will be rounded down to 16. No submissions are excluded at this stage. Thomson Reuters then excludes the 25% highest and the 25% lowest submissions of the rounded number. For the USD example cited above, this means Thomson Reuters will exclude the highest four (25% of 16) and the lowest four submissions. The remaining 10 (=18-4-4) submissions are simply averaged to compute the Libor for USD for any given maturity.

Table B.1: Panel banks' submission periods

This table reports the initial year/month for which Libor submissions in a given currency are available across panel banks. The sample ends in November 28, 2012, for all banks. An asterisk denotes banks that are not publicly traded.

Bank name	USD	GBP	JPY	CHF
Banco Santander (now Abbey National)	-	2001/01	-	-
Bank of America	2001/01	-	-	-
Bank of Tokyo - Mitsubishi UFJ Ltd.	2001/01	2001/01	2001/01	2001/01
Barclays	2001/01	2001/01	2001/01	2001/01
BNP Paribas	2011/02	2001/01	-	-
Citigroup	2001/01	2005/07	2002/03	2001/01
Credit Agricole	2011/02	2010/12	2010/12	-
Credit Suisse Group	2001/01	-	-	2001/01
Deutsche Bank	2001/01	2001/01	2001/01	2001/01
HSBC Hdg	2001/01	2001/01	2001/01	2001/01
JP Morgan Chase & Co.	2001/01	2001/01	2001/01	2001/01
Lloyds Banking Group	2001/01	2001/01	2001/01	2001/01
Mizuho	-	2009/02	2001/01	-
Norinchukin*	2001/01	-	2001/01	-
Rabobank*	2001/01	2001/01	2001/01	2009/06
Royal Bank of Canada	2005/07	2003/03	-	-
Royal Bank of Scotland Group	2001/01	2001/01	2001/01	-
Societe Generale	2009/02	2010/06	2006/01	2001/01
Sumitomo Mitsui Banking Corporation	2011/02	-	2001/01	-
Union Bank of Switzerland	2001/01	2001/01	2001/01	2001/01

Table B.2: First stage results of TSLS analysis

This table reports the estimates of the first-stage regression of changes in Libor on changes in the corresponding currency-maturity risk-free rate of a given country, domestic aggregate stock market returns, and changes in VIX. The last two rows report the corresponding F-test of overidentifying restrictions and their corresponding p-values.

Variable	USD-1m	USD-3m	USD-6m	GBP-1m	GBP-3m	GBP-6m	JPY-1m	JPY-3m	JPY-6m	CHF-1m	CHF-3m	CHF-6m
Δr_f	0.664***	0.699***	0.730***	0.793***	0.784***	0.753***	0.484***	0.280***	0.192***	0.804***	0.810***	0.798***
	(6.157)	(7.845)	(14.224)	(5.738)	(5.458)	(7.702)	(3.262)	(3.619)	(3.739)	(8.960)	(8.680)	(10.564)
r_{Mkt}	0.030	-0.129	0.019	-0.012	0.018	0.025	0.033	-0.001	0.013	-0.071	-0.043	-0.008
	(0.304)	(-0.793)	(0.166)	(-0.206)	(0.330)	(0.362)	(0.540)	(-0.021)	(0.483)	(-1.346)	(-1.153)	(-0.235)
ΔVIX	0.001	0.002	0.001	-0.000	-0.000	0.001	0.001	-0.001	-0.000	0.000	0.000	0.000
	(0.637)	(0.851)	(0.792)	(-0.393)	(-0.448)	(1.127)	(1.265)	(-1.377)	(-0.701)	(0.488)	(0.520)	(0.941)
Obs.	725	725	725	725	725	725	725	725	725	725	725	725
R^2	0.7418	0.7281	0.7247	0.7707	0.7786	0.6360	0.4970	0.3596	0.2549	0.8059	0.8231	0.8037
F	34.5516	64.3660	235.9030	30.9960	30.6160	36.8490	14.3670	14.1300	13.3013	80.2377	77.4266	114.2900
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0003	0.0000	0.0000	0.0000